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CIRA ICING WIND TUNNEL USER MANUAL

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Ferrigno Francesco (IWTU)	**Ferrigno Francesco (IWTU)**	**Ferrigno Francesco (IWTU)**	**Vecchione Ludovico (LMSA)**
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ABSTRACT:

THIS GUIDE PROVIDES GENERAL INFORMATION OF CIRA ICING WIND TUNNEL (IWT) TO PERSPECTIVE CUSTOMERS THAT WANT TO CONDUCT ICING TESTS IN THE FACILITY. TECHNICAL DESCRIPTION OF THE FACILITY, AS WELL AS AVAILABLE SERVICES AND CAPABILITIES ARE HEREIN DESCRIBED, INCLUDING CIRA ICING ACTIVITIES SUPPORTING THE ICING WIND TUNNEL.
GUIDELINES OF STANDARD PRACTICES AND PROCEDURES TO HELP PERSPECTIVE CUSTOMERS IN REQUIRING IWT SERVICES AND EASILY ACHIEVE THEIR TEST OBJECTIVES ARE ALSO DESCRIBED.

AUTHORS:

FERRIGNO FRANCESCO; ESPOSITO BIAGIO;ESPOSITO GIUSEPPE;VERNILLO PAOLO;RAGNI ANTONIO;CASERTA GIANPAOLO;BELLUCCI MATTEO;MARRAZZO MARCO;DINARDO MARIO;DE GREGORIO FABRIZIO;AULETTA ANTONIO;ALBANO FLORIANA

APPROVAL REVIEWERS:

FERRIGNO FRANCESCO;

APPROVER

FERRIGNO FRANCESCO

AUTHORIZATION REVIEWERS:

AUTHORIZER

VECCHIONE LUDOVICO

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1.0 PURPOSE

This guide provides general information of CIRA Icing Wind Tunnel (IWT) to prospective customers that want to conduct icing tests in the facility. Technical description of the facility, as well as available services and capabilities are herein described, including CIRA icing activities supporting the IWT.
Guidelines of standard practices and procedures to help prospective customers in requiring IWT services and easily achieve their test objectives are also described.

2.0 INTRODUCTION

C.I.R.A., the Italian Aerospace Research Center, is a shareholding Consortium, operating according to the guidelines provided by the Italian Ministry of Education, University and Research (MIUR). More information can be found in CIRA website: http://www.cira.it.
CIRA is located in Capua, a small city near Caserta, about 200 kilometers south of Rome and 50 Kilometers north of Naples. Customers can arrange their trip to CIRA with a flight either to Rome (Fiumicino Airport) or to Naples (Capodichino Airport). CIRA can be reached from Naples airport by taxi. Transports to/from CIRA site can be also arranged upon request. Hotels with special fares for CIRA customers are available in the area.

The Icing Wind Tunnel is part of a brand new complex including ground testing facilities and dedicated utilities making up the Italian Aerospace Research Centre.

Fig. 1: CIRA aerial view

Fig. 2: Icing Wind Tunnel aerial view

3.0 LIST OF ACRONYMS

ADA	Airborne Droplet Analyser
CIRA	Centro Italiano Ricerche Aerospaziali
DAFE	Data Acquisition Front End
DAS	Data Acquisition System
EBS	External Balance System
EFS	Engine Flow Simulator
FAR	Federal Aviation Regulation
FMS	Facility Management System
FRS	Flow Reference System
FS	Full Scale
IB	Icing Blade
IWT	Icing Wind Tunnel
LDV	Laser Doppler Velocimetry
LWC	Liquid Water Content
MSS	Model Sting Support
MVD	Median Volumetric Diameter
MW	MegaWatt
PDPA	Phase Doppler Particle Analyser
PIV	Particle Image Velocimetry
Ps	Static Pressure
PSP	Pressure Sensitive Paint
Pt	Total Pressure
PTS	Probe Traversing System
q	Dynamic Pressure
rpm	Round per Minute
RH	Relative Humidity
SBS	Spray Bar System
SLD	Super-cooled Large Droplets
SW	Software
TAL	Test Automation Language
TAS	Test Automated Scripts
UPS	Uninterruptible Power Supply
V	Velocity

4.0 GENERAL INFORMATION

Officially inaugurated in September 2002, the CIRA Icing Wind Tunnel (Fig. 3) broke a number of world records. Among these, the following ones can be reminded:

- is the largest refrigerated wind tunnel in service;
- is the highest speed icing wind tunnel (M=0.7);
- is the only facility combining altitude, humidity and temperature simulation;
- has the largest number of different test sections configurations (4);
- has the largest numbers of spray bar nozzles (500) and bars (20);
- has the widest operating range for engine flow simulation (1.5-55 kg/s mass flow).

Fig.3: CIRA Icing Wind Tunnel

Located in the stilling chamber, the Spray Bar System (SBS) is dedicated to the generation of the icing cloud in all the conditions as prescribed in the current FAR/JAR regulations. Looking at future revisions of the airworthiness regulations, the SBS is also capable to generate Super-cooled Large Droplets (SLD) within the range of freezing drizzle conditions.

Thanks to the capability of a fully remote control of the test, it is also possible a fast switching from “Max continuous” cloud conditions to “Max intermittent” cloud conditions.

Other advanced systems ensure the best simulation of possible natural icing conditions, e.g. a twin row heat exchanger for temperature simulation down to –40 °C, a de-pressurization system for altitude simulation up to 7,000 meters (about 23,000 feet) and an humidity control down to 70% RH.

The CIRA IWT is equipped with four different test section configurations in order to satisfy all the test requirements in terms of speed, model size, cloud coverage and uniformity.
Slotted walls configuration of the test sections allows high blockage testing capabilities and extended run-time (up to 180 minutes).

The Additional Test Section (ATS) and the Open-Jet Test Section are large enough to allow the installation of scaled model (Fig. 4), or full-size airframe components, such as wing sections, tail sections and nacelles.

In most cases, the test section sizes allow the use of a full scale model or even a pre-production mock-up.

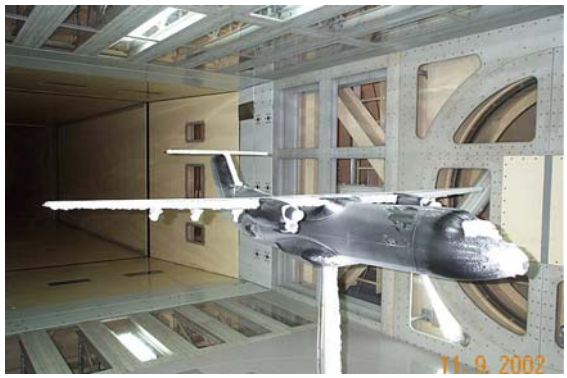

Fig.4: Aircraft model in the ATS

Full-scale airplane (Fig. 5) and helicopter (Fig. 6) air intake mock-up have been already successfully tested in the Main Test Section (MTS).

Finally, the high speed achievable in the Secondary Test Section (STS) makes this configuration particularly suitable for helicopter blades testing.

Fig.5: Full-scale aircraft air-intake icing tests

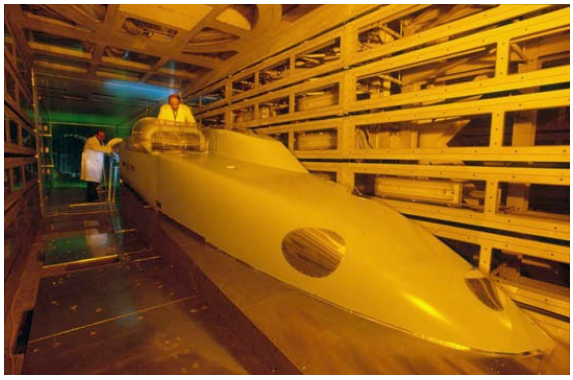

Fig.6:Full-scale helicopter air-intake installation

Generally, the CIRA IWT can perform qualification and compliance tests for a variety of anti-ice and de-ice systems, including boots, hot bleed air and thermal resistance systems. Thanks to a dedicated engine flow simulation system, it is also possible to perform airplane/helicopter air intake icing qualification tests in a wide operating range.
Ice accretion tests, including the study of performance degradation effect on 2D, 2.5D and 3D models are also possible, as well as qualification tests on a wide variety of instrumentation, such as ice detectors and probes.

As a further capability, CIRA IWT is able to perform high flow quality aerodynamic tests in both low and high subsonic range, at Reynolds number comparable to much larger facilities, by exploiting its low temperature operating range and pressurization capability up to 1.45 bars.

Pressure and force measurements on 2D, 2.5D and 3D models, as well as Laser diagnostic measurements (PIV, LDV) can be performed in the aerodynamic configuration.

4.1 LOGISTICS

The IWT area is made of the following buildings, besides the wind tunnel itself: offices building, parking hall and auxiliary systems building. A general layout of the area is shown in Fig. 7.

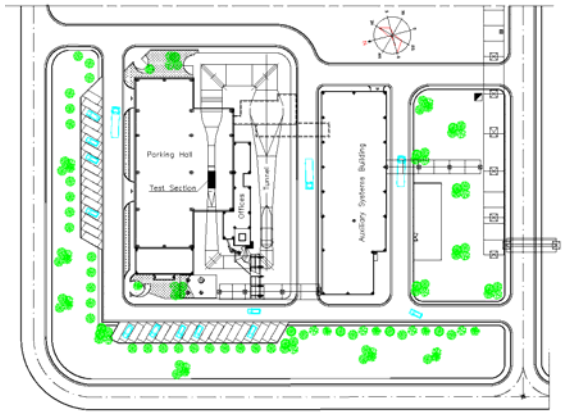

Fig. 7: Icing Wind Tunnel area layout

The building hosting the auxiliary systems (air plant and cooling plant) is located nearby the wind tunnel, opposite side of the parking hall area (Fig. 7).

Two areas for car parking are located at the entrance of the offices' building and at the entrance of the parking hall.

A three floors building is located in the middle of the wind tunnel circuit. Its function is to host operating team and users offices, the laser room (ground floor) and the facility control room.
The control room is located on the first floor, where access to the test section is granted through an air lock chamber (Fig. 8). Control room equipment includes video camera monitors, video recording equipment, operators' consoles and the engineering and data acquisition hosts which provide complete information about test and model

conditions. A PC for specific model data acquisition is also available to the customer.

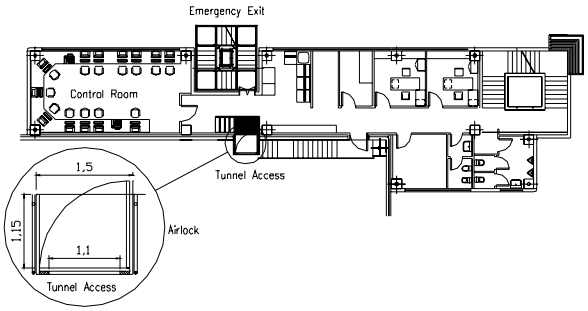

Fig. 8: Control room and offices layout

A large parking hall (18 by 54 meters, Fig. 9) allows the storage of different interchangeable components. A dedicated area is also available for tunnel configuration changes and/or model preparation. Three workshop areas are located on one side of the parking hall for customer work and model preparation in complete privacy.

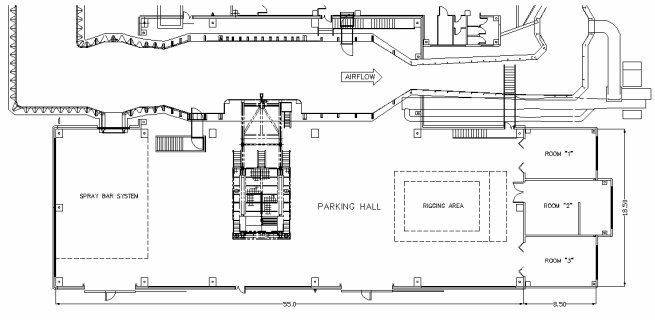

Fig. 9: IWT Parking Hall Layout

Model/wind tunnel preparation for a specific test campaign is completely performed inside the parking hall.

Before a specific test, the selected test section is positioned in the Test Section Rigging Area, near the workshop rooms, for model installation (Fig. 10).

Fig. 10: Test Section in the rigging area

Model assembly and preparation, instrumentation and test equipment installation can be performed with no other access limitation than the test section dimension itself. After model and test instrumentation checks, the test section is lifted via an overhead bridge crane and located onto a slide running on raised rails. From that position, the test section is then pushed into the plenum chamber until reaching its final position, ready for testing.

4.2 IWT ORGANIZATION

The Icing Wind Tunnel is part of the Icing Test Laboratory. This laboratory is included in CIRA Aeronautical Ground Testing Facilities Department (Fig. 11).

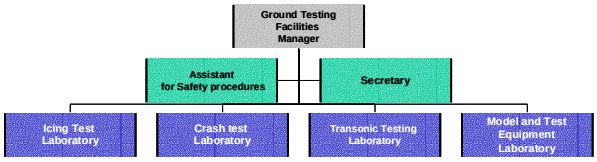

Fig.11: Ground Testing Facilities Organization

The Icing Test Laboratory is made of a highly qualified team of 14 people distributed in five areas, as shown in Fig. 12.

An external crew is full-time dedicated to the facility for mechanical and electrical operations during the installation phase, for assistance during the tests and for operation of the auxiliary plants.

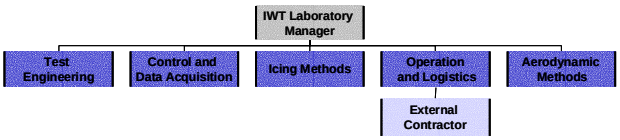

Fig. 12: Icing Test Laboratory Organization

4.3 QUALITY ASSURANCE

The Icing Wind Tunnel develops its activities within the frame of the CIRA Quality Management System, in compliance with the UNI EN ISO 9001:2000 standard.
CIRA was granted, in 2003, by UNAVIAcert (EA21 SINCERT accredited Certification Body) of the conformity certificate n.069 to the above mentioned standard for: *"Research, Development and Experimental activities in the fields of Aeronautics and Space; Development of fixed and rotor wing and space flight demonstrators; testing activities in the Aeronautics and Space fields; aeronautical systems performance verification".*
Moreover, for each testing contract, a Quality Plan is prepared before the beginning of the activities. This document, besides satisfying any eventual customers' peculiar request not already dealt within CIRA Quality Manuals, represents the basis for systematic internal audits.

5.0 WIND TUNNEL DESCRIPTION

5.1 GENERAL DESCRIPTION

The IWT facility is a closed loop circuit, refrigerated wind tunnel, with three interchangeable test sections and one Open Jet configuration. A schematic of the IWT is shown in Fig. 13.
As many conventional wind tunnels, the IWT is fan driven. The fan and the fan drive are located downstream corner 2, in the back leg. Downstream the fan diffuser, a twin row heat exchanger is located to provide low temperature operation capability. The facility settling chamber is fitted with a honeycomb module to reduce large scale eddies thus ensuring flow straightening. Downstream the honeycomb, an interchangeable section provides the possibility to install either:

- a spray bar module generating the cloud for icing tests or
- a screen module when lower turbulence airflow is necessary for high quality aerodynamic tests.

The distance between the SBS and the model location is 18 meters. Downstream the fixed contraction, the test section leg is made up of two interchangeable components (movable contraction + test section) and a variable geometry collector diffuser.

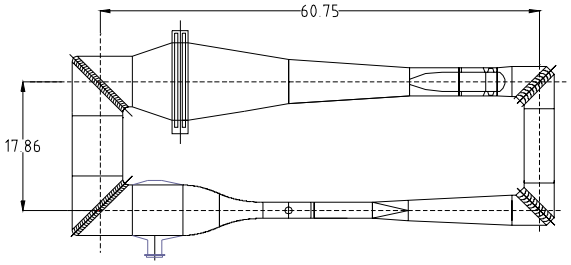

Fig. 13: Icing Wind Tunnel layout

5.2 COOLING SYSTEM

The function of the Cooling System (fully dedicated to the facility) is to remove the heat generated by the different heat sources and to keep constant temperature values. Air flow refrigeration is obtained via a twin row Heat Exchanger located in the back leg, upstream the third corner, and back stream the main fan.

The cooling plant is made up of 4 compressor units (1700 kW motor power each), a single evaporator and a single condenser unit, the twin row heat exchanger, connecting pipes and specific auxiliaries (e.g. pumps and valves). Compressors, evaporator and condenser units are located in a separate building just facing the heat exchanger section (Fig. 14).

The used cooling media are the environmental compliant R507 and the Therminol Oil “brine”.

Fig. 15: Detail of the Cooling Plant

The minimum achievable temperature is –32°C in the Main Test Section and in the Additional Test Section. The Secondary Test Section can get down to –40°C.

Temperature is controlled via the FMS. Accuracy on the set-point is ±0.1°C. Temperature descent rate is up to 1°C/min. Fig. 15 shows some results of temperature stability tests.

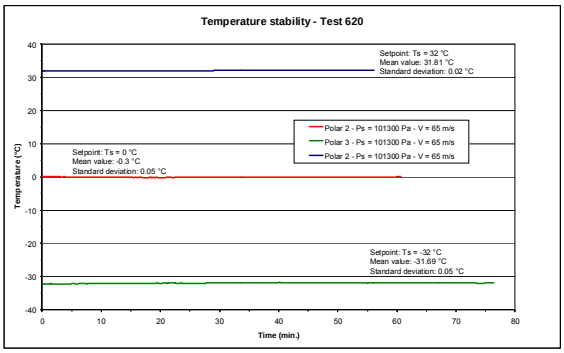
Temperature stability - Test 620
Setpoint: Ts = 32 °C
Mean value: 31.81 °C
Standard deviation: 0.02 °C
Polar 2 - Ps = 101300 Pa - V = 65 m/s
Polar 3 - Ps = 101300 Pa - V = 65 m/s
Polar 2 - Ps = 101300 Pa - V = 65 m/s
Setpoint: Ts = 0 °C
Mean value: -0.3 °C
Standard deviation: 0.05 °C
Setpoint: Ts = -32 °C
Mean value: -31.69 °C
Standard deviation: 0.05 °C
Temperature (°C)
Time (min.)

Fig. 15: Temperature stability at V, p = const.

The Heat Exchanger is also capable to control the air Relative Humidity (RH) before the spray bar, by means of a hot air compressor and steam injection. Controlled humidity ranges between 70% and 100% for temperatures between –15°C and –20°C. 100% humidity value can be set between –20°C and –40°C. Control accuracy is within ± 5% RH.

Finally, by circulation of hot brine in the same heat exchanger, the cooling system is capable to de-ice the heat exchanger itself after an icing test and to make available the “Tunnel De-icing” operation mode.

Fig. 16: Heat Exchanger section

5.3 AIR PLANT

An air plant is fully dedicated to the IWT in order to provide facility operation support.

A 0.7 MW centrifugal compressor unit allows the pressure to be regulated between 0.39 bars (corresponding to an altitude of 7000 meters) and 1.45 bars. Safety valves allow a fast tunnel evacuation and pressurization.

Altitude is controlled by a specific task of the FMS through pressure, velocity and temperature control. Accuracy on altitude set-point is 10 meters. Fig. 17 shows some results of pressure stability tests.

Controlled depressurisation ramp from sea level for altitude simulation is 200 m/min, whereas altitude descent up to sea level can be performed at a rate of 150 m/min in controlled mode or 400 m/min in “fast evaporation” mode.

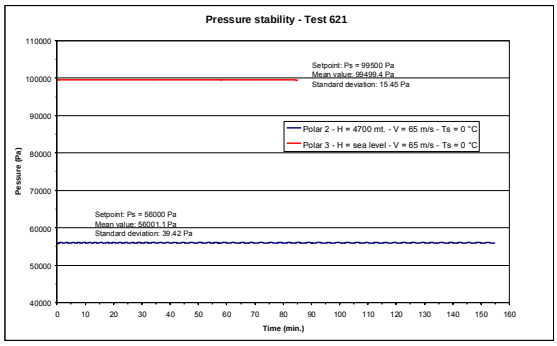
Pressure stability - Test 621
Setpoint: Ps = 99500 Pa
Mean value: 99499.4 Pa
Standard deviation: 15.45 Pa
Polar 2 - H = 4700 mt. - V = 65 m/s - Ts = 0 °C
Polar 3 - H = sea level - V = 65 m/s - Ts = 0 °C
Setpoint: Ps = 56000 Pa
Mean value: 56001.1 Pa
Standard deviation: 39.42 Pa
Pressure (Pa)
Time (min.)

Fig. 17: Pressure stability at V, T = const.

A 1.2 MW axial compressor unit supplies the SBS.

Hot air and pneumatic boot de-icing systems are supplied by the hot air de-icing compressor (0.4 MW power).

A dedicated compressor supplies the pneumatic boot impulse de-icing system.

Finally, instrument air is provided by a screw compressor, at a nominal pressure of 7.5 bars. Instrument air is available at several positions in the building, the parking hall and inside the plenum chamber.

Fig. 18: Detail of the Air Plant

5.4 FAN SYSTEM

The facility is driven at the desired airspeed by a 24 blades, variable blade pitch angle fan unit. The fan has an external diameter of 3.9 meters.

The wind tunnel speed is automatically controlled via the Facility Management System (FMS). Fan motor speed is electronically controlled by an inverter, up to a maximum fan rpm of 750.

Accuracy on Mach target is 0.1% in the range between $0.6V_{max} \leq V \leq V_{max}$ and 0.2% in the range $0.2V_{max} \leq V \leq 0.6V_{max}$.

Fig. 19 shows some results of velocity stability tests.

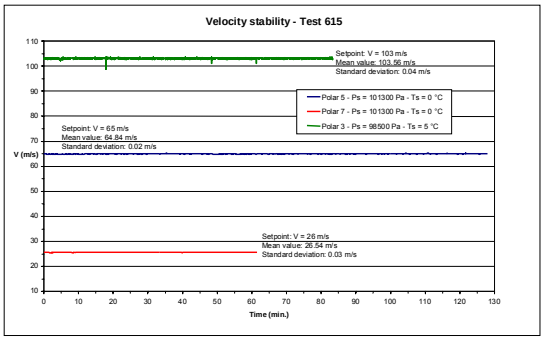
Velocity stability - Test 615
Setpoint: V = 103 m/s
Mean value: 103.66 m/s
Standard deviation: 0.04 m/s
Polar 5 - Ps = 101300 Pa - Ts = 0 °C
Polar 7 - Ps = 101300 Pa - Ts = 0 °C
Polar 3 - Ps = 98500 Pa - Ts = 5 °C
Setpoint: V = 65 m/s
Mean value: 64.84 m/s
Standard deviation: 0.02 m/s
Setpoint: V = 26 m/s
Mean value: 26.54 m/s
Standard deviation: 0.03 m/s
V (m/s)
Time (min.)

Fig. 19: Velocity stability at T, p = const.

The fan is located in the return circuit. The fan motor is located inside the fan nacelle. The motor is cooled through a dedicated air cooling system.

Upstream the fan, a grid avoids that major ice blocks could impinge on the blades.

The fan power is 4 MW, however, a 35% power margin is available to compensate pressure losses increase due to ice build up inside the wind tunnel.

Variable blade pitch angle (47 deg. range) allows an optimal setting for different aerodynamic load conditions. Fan blades have provisions for heating system.

Fig. 20: IWT Fan Blades detail

5.5 SPRAY BAR SYSTEM

The IWT Spray Bar System (Fig. 21) is able to generate water droplets with diameters (MVD) and Liquid Water Content (LWC) covering the overall envelope prescribed by the FAR 25/29 Appendix C for both continuous and intermittent cloud conditions. Furthermore, the system is capable to generate Super-Cooled Large droplets (SLD), within the range of freezing drizzle conditions.

Fig. 21: Spray Bar System

The SBS is located in the IWT stilling chamber (Fig. 22), about 18 meters upstream the centre of test section, thus assuring a droplet residence time higher enough to achieve super-cooling conditions even for large droplet sizes.

Upstream the SBS section, a honeycomb section assures straight flow conditions at the cloud generation section.

Fig. 22: Spray Bar installed in the wind tunnel

The SBS has 20 bars having a low drag aerodynamic shaped section, whose main feature is a low sensitivity to flow separation. Each bar is removable and may be vertically adjusted for optimising cloud coverage and uniformity, if necessary, during the calibration phase. Each bar is equipped with 50 spraying nozzle positions, for a maximum total of 1000 possible spraying positions over 20 bars. Normally, the system is equipped with 500 active spraying nozzles, whereas the remaining 500 nozzle positions are plugged (Fig. 23). Each nozzle water supply line is equipped with a solenoid valve that can be remotely switched on and off.
The number of operating nozzles may be changed during a run by using the Facility Management System Software.

The SBS is equipped with nozzle holders which may easily allow the installation of NASA STD nozzles. However, the SBS configuration with NASA STD nozzle is not considered as a standard installation in the CIRA IWT.

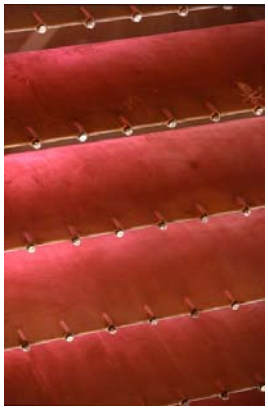

Fig. 23: Spray Bar System: bars detail

The SBS is fed by:

- pressurised, demineralised and conductivity-controlled water. The temperature T_w can be controlled up to 100 °C whereas the supply pressure can be set between $0.01 < p_w < 10$ bar (abs);
- dry compressed hot air at temperature T_a controlled up to 150 °C, dew point

–40 °C. The air pressure can be set between 0.01 < p_a < 11.5 bar (abs).

All the parts of the Spray Bar System in contact with pressurised air and demineralised water (e.g. pipes, boxes, and SBS airfoil), are made of stainless steel.

A closed loop control system managed by the FMS allows both keeping constant SBS air and water supply pressures and temperatures (and, as a consequence, MVD ad LWC values), and fast switching from Maximum Continuous to Intermittent Continuous conditions (Fig. 24), even for certification tests of engine nacelles within the JAR 25. 103 Method 1.

Once started the spraying, set point conditions can be reached within 10 seconds. Accuracy on air and water set point pressures are respectively lower than ±0.3% and ±0.6% in the whole SBS operative range.

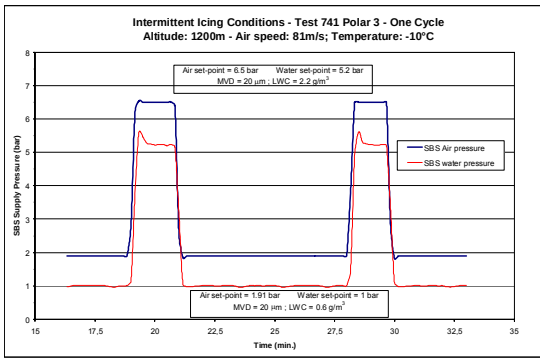
Intermittent Icing Conditions - Test 741 Polar 3 - One Cycle
Altitude: 1200m - Air speed: 81m/s; Temperature: -10°C
Air set-point = 6.5 bar
Water set-point = 5.2 bar
MVD = 20 µm ; LWC = 2.2 g/m³
SBS Air pressure
SBS water pressure
Air set-point = 1.91 bar
Water set-point = 1 bar
MVD = 20 µm ; LWC = 0.6 g/m³
SBS Supply Pressure (bar)
Time (min.)

Fig. 24: SBS intermittent pressure conditions

Figs. 25 and 26 show respectively air and water SBS supply pressure fluctuations, at different nominal set-point values.

The fluctuation is evaluated by calculating the standard deviation of the supply pressure (air and water), for each bar spraying. Such values are finally averaged in order to give the mean SBS fluctuation as a percentage of the set-point value (blue spots in the figures).

The error bars in the graphs provide the minimum and the maximum fluctuation (best and worse spraying bar) observed during a considered test. Results related to repeatability tests executed in different testing days are also included, in order to evaluate the typical expected spray bar performance boundaries (red lines in the figures).

In Fig. 25 it can be observed that air pressure fluctuation is typically less than 1% of the set-point value, and in the worse case it can go up to about the 3%, at very low set-point values.

Water pressure fluctuation is slightly higher than air fluctuation (Fig. 26), but it any case it never exceeds the 5% of the set-point value, at very low pressures.

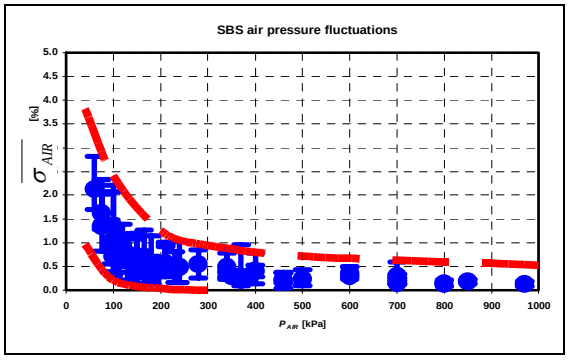

Fig. 25: SBS air pressure fluctuations at different set-points

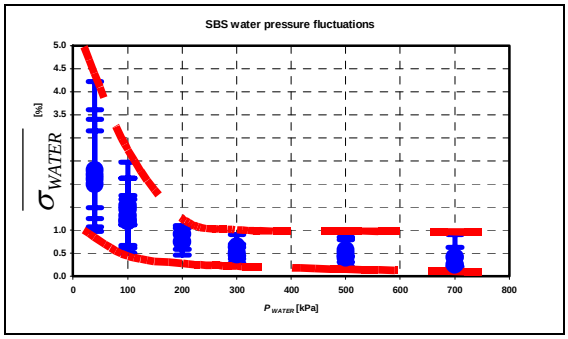

Fig. 26: SBS water pressure fluctuations at different set-points

5.6 TEST SECTIONS

CIRA IWT can be equipped with four different test section configurations. Each test section has synchronized turntables.
Three test sections have 7% porosity slotted walls in order to allow larger than usual

blockage models. Each slot has its own anti-icing system to protect its lips from ice build up and clogging. Slotted wall test sections have 80% optical access to the test model.
The fourth configuration is an open-jet test section.

Every test section configuration requires a specific contraction module, whereas the collector diffuser downstream is the same one for all test section configurations, since its two-hinge angles are adjustable to fit the specific test section size.

Contraction ratio is 6:1 for the ATS, 10:1 for the MTS and 20:1 for the STS respectively.

Fig. 27 shows the Main Test Section. A detail of the Secondary Test Section wall slot configuration is shown in Fig. 28.

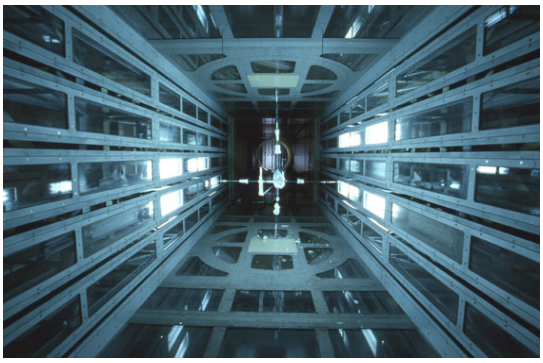

Fig. 27: Main Test Section

Fig. 28: Secondary Test Section

Tab. 1 shows the test sections' main features. Maximum achievable temperature, in any configuration, is +40°C.

	Main	Secondary	Additional	Open Jet
Height (m)	2.35	2.35	2.35	2.35
Width (m)	2.25	1.15	3.60	2.25
Length (m)	7.00	5.00	8.30	7.00
Mach	0.41	0.70	0.25	< 0.4
Temp (°C)	−32°	−40°	−32°	−32°

Tab. 1: Test sections characteristics

Mach number indicated in the table is nominally to be intended as the maximum achievable in free stream conditions (empty test section). Nevertheless, it must be considered that the maximum achievable Mach number strongly depends on the model blockage, the run-time and the icing conditions to be reproduced.

Finally, tab. 2 shows the suitability of the test sections to different kind of models.

	MAIN	SEC.	ADD.	OPEN JET
HALF MODEL	x		x	
2-D MODEL	x	x	x	x
3-D COMPONENTS	x		x	x
ENGINE SIMULATION	x		x	
ANTI/DE-ICING SYSTEM	x	x	x	x
PROBES	x	x		

Tab. 2: Model vs. suggested test sections

5.7 ENGINE FLOW SIMULATOR SYSTEM

The Engine Flow Simulator (EFS) system can reproduce the air intake flow inside an engine nacelle. Two high pressure fans are used to extract the flow through an engine nacelle installed in the test section. The sucked air flow is re-injected back into the

Wind Tunnel circuit, in the first cross leg (Fig. 29) Maximum re-injection speed in the Wind tunnel is 100 m/sec.
A flange connection between the test article and the EFS piping is located on the floor of the wind tunnel, in the diffuser region. Several piping is available for model-to-flange connection.

Both fans (fig. 30) can operate within the full wind tunnel temperature and pressure ranges. Nominal mass flow ranges at sea level altitude for the two EFS systems, at the floor connection flange, are:

- EFS#1: 15 to 55 kg/sec
- EFS#2: 1 to 15 kg/sec

The air mass flow is accurately metered by a twin calibrated Venturi system in order to ensure the required accuracy within the whole mass flow range. A maximum error of 1% order is thus ensured in the mass flow range between 1 and 55 kg/s.

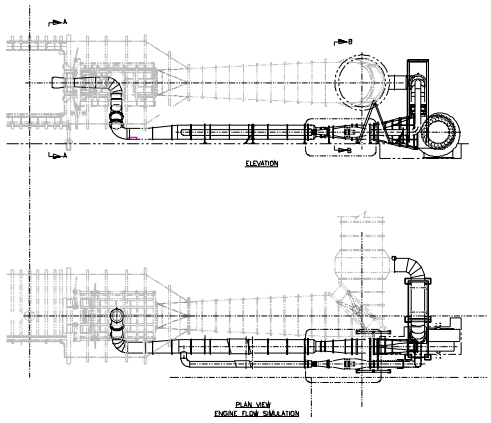

Fig. 29: EFS System Layout

Fig. 30: EFS housing

6.0 AUXILIARY SYSTEMS

6.1 HOT AIR DEICING SYSTEM

In case hot air de-icing operation is required during a test, the model de-ice system can be operated using a dedicated feeding provision located inside the plenum chamber. The operating conditions of the system can be kept constant during the test or changed by simulating duty cycles of actual aircraft ice protection system operations.
The de-icing air flow conditions are measured and controlled through the full range at the plenum feeding location. Table 3 shows current hot air de-icing system performances.

	Range	Accuracy
Mass flow rate Max Temperature	0.1 to 1.5 kg/s 300 °C	2 g/s ±5°C
Mass flow rate Max Temperature	0.1 to 0.54 kg/s 400 °C	2 g/s ±5°C
Pressure	up to 3 bars gauge	±0,05 bar

Tab. 3: Hot air de-icing system performances

All these parameters are measured and controlled by the FMS.
CIRA is currently designing an upgrade of the line that will pressure up the line to 9 bar g and will guarantee a minimum mass flow of 0.01 kg/s at 400°C. The accuracy on target and on measurement will be upgraded to ±1 °C and ±0.01 bar; temperature rate will be higher than 10 °C/min.

6.2 PNEUMATIC BOOT SYSTEM

CIRA IWT allows typical pneumatic boot operations thanks to a dedicated pneumatic boot line. The line is supplied by the hot air de-icing compressor and tank, but it is fully independently controlled. Table 4 shows

current pneumatic boot de-icing system performances.

	Range	Accuracy
Mass flow rate	0.015 kg/s max.	3%
Temperature	20 ÷ 200°C	±5 °C
Pressure	up to 3 bar gauge	±0,05 bar gauge

Tab. 4: Pneumatic boot system performances

All these parameters are measured and controlled by FMS.
CIRA is currently designing an upgrade of this line that will increase the maximum mass flow to 0.3 kg/s and the temperature to 400 °C. Accuracy on target and on measurement will be upgraded to ±1 °C and ± 0.01 bar respectively.

6.3 PNEUMATIC BOOT IMPULSE SYSTEM

Air pressure is provided for conventional pneumatic boot impulse systems. The system is equipped with a compressor and a storage tank. The system provides high pressure impulses of 50 bars with a mass flow of $5x10^{-3}$ kg/s.

6.4 ELECTRICAL DE ICING SYSTEM

Provision for electrical ice protection on the model is available in the plenum chamber. The main characteristics of the system are reported below:

- Voltage: 115/200V AC @ 400 Hz
  Power: 20 kW
- Several Voltage: 400/230V AC @ 50Hz
  17 Power Supply Available for a Total Power of 350 kW
- Voltage: 24-32 adj. VDC
  Power: 20 kW

Both continuous and intermittent power can be provided. The system has a flexible duty cycle capability in case of such a requirement for specific tests.

6.5 STEAM SUPPLY

Steam provisions are available at fixed locations in the plenum for the following uses:

- model and wind tunnel sections defrosting operations;
- model de-ice systems supply.

Steam nominal temperature is 190 °C at a maximum pressure of 10 bars.

7.0 TEST EQUIPMENTS

7.1 TURNTABLE ASSEMBLIES

The function of the turntable assemblies (Fig. 31) is to allow different model installation in the different test sections. Each assembly is made-up of a square frame which includes a 2 meters diameter rotating platform. Different installations are possible in the different test sections:

- the Main Test Section allows a vertical model mounting having the turntables on the floor and on the ceiling;
- the Secondary Test Section allows an horizontal model mounting having the turntables on each side-wall;
- the Additional Test Section allows a horizontal model mounting having turntables on each side-wall;
- the Open Jet configuration allows a vertical model mounting. This configuration has the turntables mounted on the plenum shell.

The turntables can be rotated within a rotation angle range from -100^{o} to $+250^{o}$ degrees, in a synchronous mode.

The model mounting plate can be adapted for IWT user model interface or changed with a user customized interface.

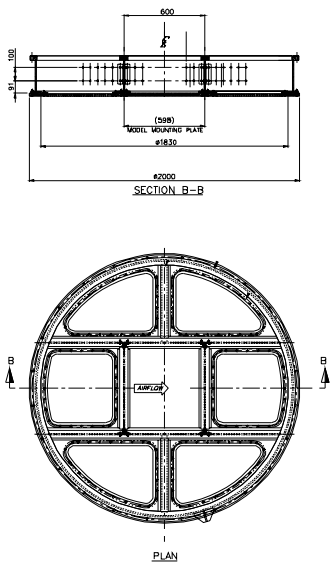

Fig. 31: Turntable assembly

Maximum allowed live loads on the turntables are:

Fx = 14.7 kN, Mx = 21.8 kNm
Fy = 4.9 kN, My = 14.1 kNm
Fz = 86 kN, Mz = 2.25 kNm

Orientation is referenced to global test section co-ordinates: x for stream-wise axis, y for lateral axis, z for vertical axis.

7.2 MODEL STING SUPPORT

The Model Sting Support (MSS) is an arc sector type, with reference point at the test section center. It has been designed in order to support the model weight and the aerodynamic loads generated by model aircraft, with the minimum possible flow interference (see Fig. 32).

Fig. 32: Acceptance of Model Support System

The MSS can be used in the MTS and in the ATS within a temperature range of $-32°C \div +40°C$, even during icing tests.

The allowable load ranges are the same as the ones of the external balances (section 7.4). The maximum allowable weight of the model shall be 3KN.

The MSS rotations are controlled in a remote way, except for roll angle. Motion ranges, at the model center, are the following:

- Pitch angle (α): $\Delta\alpha = -15°\div+45°$ deg. using straight sting and $-15°\div+90°$ using bent sting ($\pm$ 0.02° accuracy);
- Yaw angle (β): $\Delta\beta = -170°\div+180°$ deg. ($\pm$ 0.04° accuracy);
- Roll angle (γ): $\Delta\gamma$ = 0°÷360° (only manual mode).

The maximum rotation speed is 2°/min. Natural frequency is 7 Hertz.

The system allows the installation of cabling from model instrumentation and other equipment needed for powered models testing.

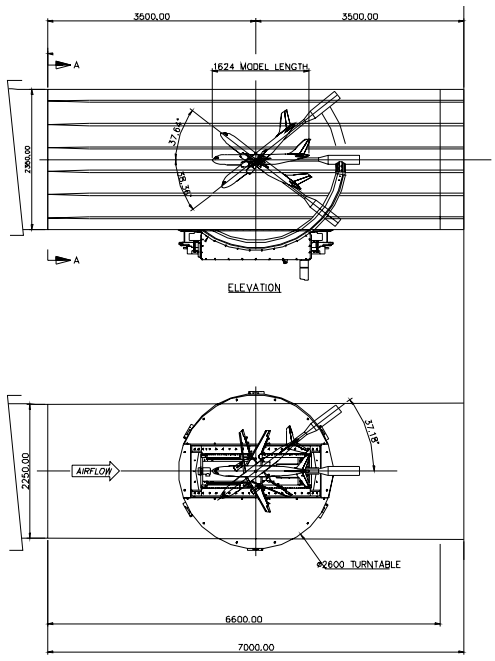

Fig. 33: MSS movement range for a typical aircraft model

7.3 PROBE TRAVERSING SYSTEM

The Probe Traversing System (PTS) allows three dimensional movements along x, y and z axis. It can be used either in the MTS, the STS and the ATS.

A wide variety of probes can be fitted at the PTS far end. The PTS is able to cover about the 90% of the test section height and width and can be used during icing tests too.

Longitudinal positioning along stream direction (X axis) can be achieved by installing boom extensions (spool sections). A fine positioning is achieved by means of remote telescopic extension up to a 400 mm longitudinal traversing.
Y and Z traversing are achieved in a remote way. Positioning accuracy in all the directions is lower than 0.2 mm.

Maximum carrying weight of PTS is 30 Kg.

The frame hosting the PTS is installed at the very end of the test sections. A dummy frame is fitted downstream the test section when the PTS is not installed.

Fig. 34: Instrumentation installed on PTS in the Main Test Section

7.4 EXTERNAL BALANCE SYSTEM

The IWT is equipped with a high accuracy virtual pyramidal type External Balance System (EBS), allowing both step pause and sweep mode motions with positioning accuracy of 0.005 deg. The EBS can be used both in the MTS and in the ATS, with the wind tunnel operating in aerodynamic mode (water off).

The EBS is capable to operate at low temperatures, down to −32°C, for high Reynolds measurements, since it is thermally insulated and temperature controlled.

When using the external balance, the test section floor used for icing tests is replaced by another floor having a turntable (Fig. 35). This turntable is slaved to the balance rotation system.

The system allows the passage of cabling from model instrumentation and other equipment needed for powered model testing.

Fig. 35: Floor turntable with three pylons model mounting

The calibration of the balance is performed in a dedicated area in the parking hall, where a calibration device is permanently installed on isolated foundation (Fig. 36).

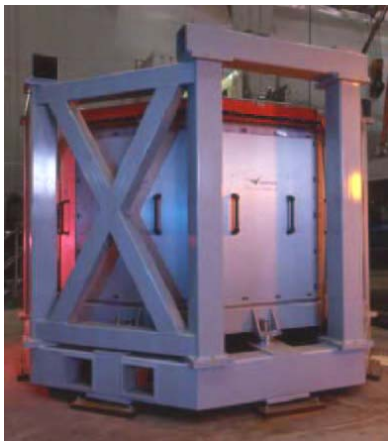

Fig. 36: EBS calibration rig

Two types of supporting frames are available:

- a three pylons model mounting;
- a half model mounting.

The first mounting assembly (Fig. 35) allows maximum model weights of 300 Kg.
It also includes a telescopic strut system which has an adjustable height in the range:

$$Z = 500 \div 1350 \text{ mm}, \Delta z = 5 \text{ mm}$$

Three fixation points, between the two main pylons (side) and between the front and rear struts, allow the installation of models with different size.

Model positioning ranges and accuracy (wind-off conditions) are:

Pitch angle (α)	-30°÷ +45°
Yaw angle (β)	-170°÷ +180°
Accuracy (α and b)	0.005°
Step	0.05°
Speed	0.1°/s÷2°/*sec*

The maximum allowable loads of the external balance system are:

- Three pylon model mounting:
  Z = 8150 N, My = 1600 Nm
  X = 2900 N, Mx = 1200 Nm
  Y = 1650 N, Mz = 1550 Nm

- Half wing model:
  Z = 11644 N, My = 3296 Nm
  X = 2825 N, Mx = 9810 Nm
  Y = 0 N, Mz = 2158 Nm

The balance accuracies are the following:

⇒ Drag (X): 0.05% FS
⇒ Lift (Y): 0.1% FS
⇒ Side Force (Z): 0.1% FS
⇒ Mx: 0.2% FS
⇒ My: 0.1% FS
⇒ Mz: 0.05% FS

8.0 FACILITY MANAGEMENT SYSTEM

The Facility Management System (FMS) is the primary control system of the CIRA IWT. Fig. 37 shows the overall block diagram of the IWT FMS. The FMS performs the following main functions:

- high level control of facility subsystems in manual, automatic remote or integrated mode;
- data acquisition of control, model and test parameters;
- status display of wind tunnel subsystems;
- control of video cameras, video matrix and recorders, display and monitoring of camera pictures;
- supervision and monitoring of the overall operation of the IWT.

The IWT FMS is based on a distributed system.
The control software running on all the subsystem PC's is based on the Talent V4 kernel of React. The TALENT V4 kernel provides an integrated environment for implementing a target Test Automation System.

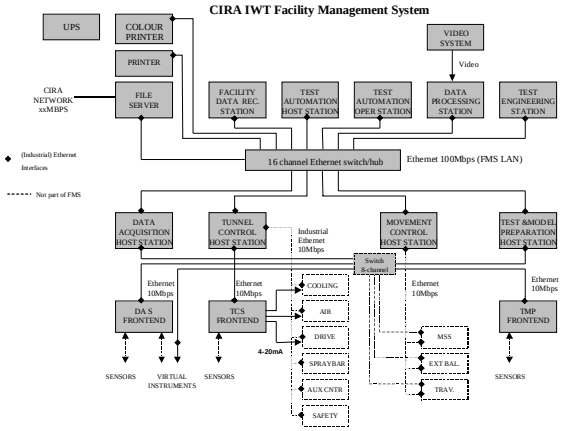

Fig. 37: IWT Facility Management System

8.1 HARDWARE PLATFORM

The host hardware platform is based on a PC network running under Microsoft Windows XP. The communication is

assured by a 1 GB Ethernet LAN. The interface to the PLC based low-level control systems (not part of the FMS) consists of an industrial Ethernet LAN.

The IWT computer network consists of a file server PC and several hosts for data acquisition, facility data recording, data processing, test engineering, tunnel control, test automation, movement control, and test & model preparation.

The following data acquisition equipment is also available:

- data acquisition front-end;
- tunnel control front-end;
- test & preparation front-end.

Fig. 38 shows the layout of the PC in control room.

Fig. 38: Workstations in IWT Control Room

8.2 TUNNEL CONTROL SYSTEM

The Tunnel Control System (TCS) performs the high-level control of the air stream parameters. It also integrates the control PLC's into the Facility Management System. Specifically, the TCS directly controls or provides interfacing at FMS control level for wind tunnel parameters, auxiliary systems, data acquisitions, safety parameters.

The Tunnel Control Host workstation also manages the control loops of the tunnel subsystems.

8.3 TEST AUTOMATION SYSTEM

During the test phase, the wind tunnel can be operated at different control levels whose main difference is the automation level of the control tasks.

The Test Automation System controls automation procedures during the different steps of the run execution phase, i.e. start-up, testing and shutdown. It also controls of the tasks not directly related to the testing activity.

The Test Automation Host station is mainly used to run the Test Automated Scripts. Furthermore, different general software applications, like process manager and logger, runs on this station.

8.4 DATA ACQUISITION SYSTEM

The IWT Data Acquisition System (DAS) is fully dedicated to test article and wind tunnel measurements. Main components of the system are:

- the Data Acquisition Front End;
- the Data Processing (sub)System.

The system can acquire both digital and analog data. Analog data during a test are conditioned, A/D converted and acquired by the Data Acquisition Front End, and finally converted in engineering units by the Data Acquisition Task. The Data Acquisition Host performs other acquisition tasks on data coming from Probe Traversing System, External Balance System, Model Support Sting and other instrument devices (i.e. Virtual Instruments).

The Facility Data Recording System is used to record facility and subsystems parameters during a run. The data can be visualized and/or logged.
Max data recording rate is 10 Hz. Averaging and decimating functions are also available.

8.4.1 Data Acquisition Front End

The Data Acquisition Front-End (DAFE) provides conditioning of:

- general purpose analogic inputs (64 channels);
- thermocouples inputs (160 channels);
- digital inputs/outputs (64 channels);

- analogic inputs (64 channels).

The conditioning includes amplification, filtering and excitation. Each channel is scanned at 200 Hz.

The DAFE system is also equipped with two channel calibrators (AC-DC).

The IWT DAFE is based on PXI/SCXI commercial equipment. The PXI part is equipped with off-the-shelf components, as well as custom made excitation and distribution racks, providing up to 16 high accuracy excitation suppliers, in order to power sensors which may be located in the test model.
Applications are based on Labview software.

8.4.2 Data Processing System

The Data Processing (sub)System (DPS) assures delivering of both raw and post-processed data in the user required form. The DPS may process both facility and test article data.

The DPS operates during the run execution phase and the post-run analysis phase. Depending on the testing phase, the data may be printed, plotted and visualized on screens, and finally incorporated in test reports. Specific measurements on the test article may be also included in the DPS data.
Data can be also directly originated from the video frame grabber unit as digital images. For the data processing tasks, standard software packages, e.g. Excel and Matlab, are available.

Two kind of data processing, on-line and off-line, are available on IWT DAS, both implemented on Data Processing Host.
The on-line data processing is made available at test preparation time. Parameters to be on-line acquired and visualized are configured in I/O configuration files before starting the recording. The on-line visualizations are fully configurable on customer request.

The off-line processing is also performed on the Data Processing Host, where a Matlab Software package runs.

8.5 VIRTUAL INSTRUMENT COMMUNICATOR

The Virtual Instrument Communicator (VIC) runs on the Data Acquisition Host. The VIC offers the possibility to send and to receive data to/from Virtual Instruments (VI). Messages are sent to the Virtual Instruments and data returned by VI are interpreted and used by the Data Acquisition system for storage, on-line processing or VI status monitoring.

9.0 INSTRUMENTATION

This section describes the instrumentation used and/or available for specific measurements during a test. The instrumentation is divided into three main categories:

- wind tunnel instrumentation;
- icing instrumentation;
- aerodynamic instrumentation.

9.1 WIND TUNNEL INSTRUMENTATION

The wind tunnel instrumentation is used for all facility operations. These on-board instruments are mainly managed by the FMS for flow measurements and facility control tasks.

9.1.1 Flow Reference System

The airflow conditions (velocity, pressure, temperature) are measured in the stilling chamber via the Flow Reference System (FRS) sensors. The FRS sensors are installed in the stilling chamber, downstream the spray bar system location. Measured data are controlled by the FMS.

Pressure measurements are performed by a MENSOR system linked to the front end with relative accuracy of 0.01% within the range 0-150000 Pa.

Temperature is acquired by means of two BFGoodrich Aerospace sensors, type 102AH2AF. These sensors have de-icing capability. The 102AH2AF probes have a PT500 resistance thermometer operating in the range of –50 °C to 150 °C with accuracy of 0.07°C.

Humidity level measurement is performed by means of two polymer film sensors installed upstream the spray bar at honeycomb section. The transducer is equipped with a microprocessor which allows calculating linear functions of the performed measurements.

Data coming from the FRS allows measuring, processing, reducing, logging and displaying the primary wind tunnel parameters (accuracy is reported within brackets):

- Velocity (< 0.5 %)
- Mach number (< 0.1%)
- Absolute/differential pressure (0.01%)
- Total temperature (< 0.1° C)
- Relative Humidity (± 3%)

The FMS uses these primary wind tunnel parameters for setting and controlling test conditions (velocity, temperature, altitude, EFS mass flow) and all the secondary parameters characterizing auxiliary systems operations.

9.1.2 Pressure Scanner System

Pressure measurements on the model can be performed by using an Electronically Scanned Pressure system (ESP) from Pressure System, Inc. The facility is equipped with a PSI 8400 system which is currently capable to acquire up to 1024 pressure ports. Configuration software has been developed by CIRA and is used to fit specific tasks. Main features of the IWT PSI System 8400 are:

- pressure scanning up to 50,000 channels/sec.;
- raw data throughput up to 50,000 channels/sec.;
- engineering Units throughput up to 50,000 channels/sec.;
- up to 300,000 bytes per second data transfer (GPIB).

The pressure transducers are miniaturized ESP pressure scanner modules, with 32 silicon pressure ports each, whose analog outputs are multiplexed and amplified within the scanner module. ESP modules have digital temperature compensation, including factory calibration data.
The following ESP modules are currently available at CIRA IWT:

- One module ±10'' water inch
  (32 ports, accuracy: 0.06% FS)
- Two modules ±5 PSI
  (64 ports, accuracy: 0.03% FS)
- Two modules ±15 PSI
  (64 ports, accuracy: 0.03% FS)

9.1.3 Video Imaging

The test performed can be documented by means of video and imaging reporting. Both optical and digital imaging may be recorded during the run.

Five video cameras are positioned inside the plenum chamber, looking at the model from different viewpoints. The video images are displayed on the monitors in the control room. Different recording formats are available. Specific customer requests can be agreed before a test.
Other five cameras are also installed along the wind tunnel circuit in order to monitor critical sections of the facility.

The following features are available:

Digital imaging: one digital camera is available for model pictures after the test.

Video imaging: the visualization of the test article during a run is performed via 5 CCD cameras, having remote control for pan and tilt. Thanks to the extended optical access in the test section, there are no critical viewing limitations or condensation problems. The cameras are Panasonic model WV-CW860 A, with 1/4" super dynamic CCD, 570 horizontal lines, and are heated and protected water proof.

Video recording: the video camera output, in addition to normal viewing on the control room monitors, can be sent to the video recorders located in the control room for future reference and analysis. The IWT video system uses the PAL video standard and the VCR recordings are made in that format. The IWT video system is equipped with a video system converter, Samsung SV 3000, able to perform signal conversion in PAL M, PAL N, SECAM MESECAM or NTSC, in case of customer requirement for a different video format.
Five DVD recorders in high picture modality (XP), 25 frames/sec, are also available as alternative to VCR analogic recording.

9.1.4 Virtual Instrumentation

In case of necessity for a specific test, other instruments can be connected to FMS system as Virtual Instruments (VI). Particularly, the connection can be performed linking physically and logically the instrumentation to the Data Acquisition System. The possible physical links connections to the DAS front end are:

- Serial COM port;
- IEEE bus;
- LAN.

The logical link is performed by the Virtual Instrument Communicator Task, which is located on Data Acquisition Host.

9.1.5 Monitoring Instrumentation

The wind tunnel control instrumentation is used for detection and supervision of temperature and pressure at different locations in the wind tunnel. The data delivered by this instrumentation are used for monitoring purposes.

Temperature monitoring is performed in different sections of the wind tunnel circuit, by means of PT100 probes installed in each of the four corners, in the test section, upstream the Heat Exchanger I, between Heat Exchanger I and II and downstream the Heat exchanger II. All PT100 used are sensors class B, BS1904.

Pitot static probes are installed along the tunnel to perform pressure measurements. The total-static pressures in plenum chamber, corners, upstream, in between and downstream the heat exchangers are thus monitored.

9.2 ICING INSTRUMENTATION

An important role in the calibration of simulated icing cloud conditions has been assumed by the instrumentation. An assessment of the existing microphysics instrumentation and its upgrade is continuously performed at CIRA for a best reproduction of the atmospheric super-cooling cloud characteristics in CIRA IWT.
Used measurement techniques as well as other available instrumentation are described in the following sections.

9.2.1 Droplet Sizing Measurement Methods

In CIRA IWT, the phase Doppler method has been selected for size and velocity atomized water droplets characterization.
Measurement principle relies on light scattering interferometer principle, i.e. using light wavelength as the measurement scale, thus avoiding typical problems occurring in measurement techniques based light scattering intensity.

Nevertheless, in CIRA IWT laboratory, instrumentation for Particle Measuring Systems, such as FSSP and OAP, are also available. In the following paragraphs all available CIRA droplet size instruments are described.

9.2.1.1 Phase Doppler Particle Analyser (PDPA) Technique

Airborne Droplet Analyzer Probes (ADA)

This optical system is an internal probe, directly exposed to the icing cloud, which provides measurements of both super-cooled cloud water droplets diameter (MVD) and its velocity component in axial-probe direction.

The CIRA ADA system includes two icing probes, with different measuring range, equipped with remotely controlled electro-thermal anti-icing system, in order to avoid icing formations on probe's arms during the measurements.

The measurable droplet diameter ranges from 0.5 µm to 138 µm for standard probe (AEROMETRICS/TSI ADA100F) with 100mm of transmitting optical focal length, and from 1 µm to 1000 µm for the probe equipped with larger transmitted optical focal length (AEROMETRICS/TSI ADA100LR).

Fig. 39 shows the ADA installed during the MTS calibration tests.

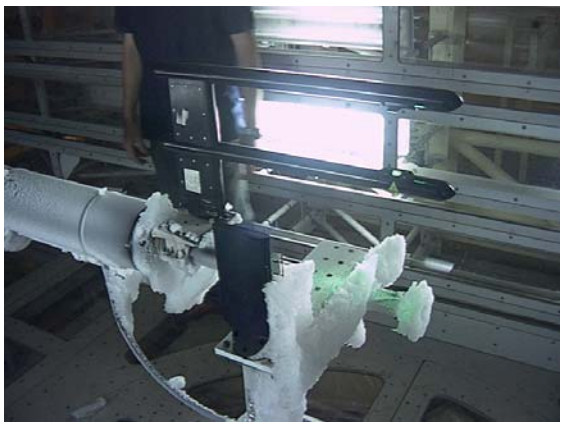

Fig. 39: ADA system installed in the IWT

External 2D PDPA System

Thanks to the available optical access on each IWT tests section, it is possible to use an external PDPA system, by installing both the transmitter (TSI TR-260-Pr-0.3) and receiver (TSI RV2200) probes externally to the test section, in the plenum chamber.

Special optical design is used for these probes, due to the large optical focal lengths. During the measurement it is possible to remotely change the optical configuration to cover a wide range of spherical droplets diameters from 0.8 µm to 2000 µm. The system can also provide the characterization of 2D droplet trajectory.

Fig. 40 shows the PDPA installed in the IWT plenum chamber.

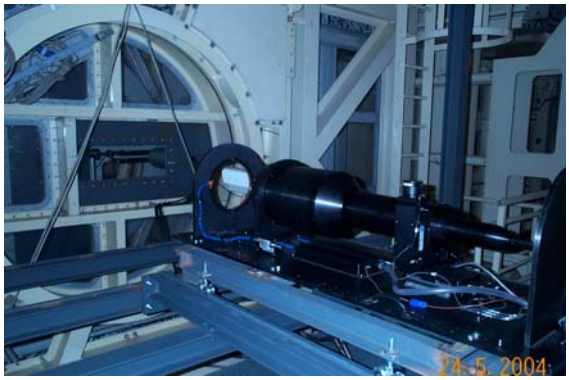

Fig. 40: PDPA system installed in the IWT

9.2.1.2 Forward Scattering Spectrometer Probe (FSSP)

The FSSP is an optical system that calculates the diameter of a droplet by measuring the power of light scattered by the droplet as it crosses the focused laser. The size of the droplet is determined by a calibration curve, which relates scattered light (Mie theory) to droplet diameter.

CIRA Icing Laboratory is equipped with a FSSP-100ER that covers a measuring range from 5 to 95µm.
The probe is mainly made of a 5 mW helium-neon laser, optics, and electronics, and works with a DMT M200 software system.

Fig. 41: CIRA FSSP-100ER system

9.2.1.3 Optical Array Probe (OAP)

The Optical Array Probe (OAP) is an optical droplet sizing instrument used to measure the water droplet diameters larger than 100µm for both natural and artificial clouds. The OAP measures the diameter of particles by using an imaging technique.

CIRA has an OAP-260X (Fig. 42) covering a range between 10 and 600µm.

As the FSSP, the OAP is a self-contained probe, approximately 1 meter long, containing a small laser. The OAP is provided with two probe arms, both heated, one containing the laser beam transmitting optics and the other one containing the receiving optics.

Fig. 42: CIRA OAP-260X system

9.2.2 Liquid Water Content Measurement Methods

Two measurement techniques, based on different measurement principles, are available for accurate measurement of cloud liquid water content (LWC).

9.2.2.1 Icing Blade System

A standard Icing Blade method is used as reference for LWC measurements during calibration of simulated icing cloud in CIRA IWT (Fig. 43).

The blade (300mm long, 60mm deep and 3mm thick) is made of stainless steel, mounted inside a deployable shield and attached at the end of the support.

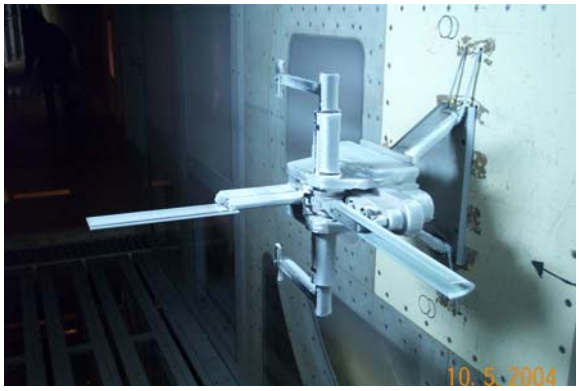

Fig. 43: Icing Blade mounted in the IWT STS

The shield is connected to an actuator. The release of the actuator runs out the shield from the blade in 0.18 seconds.

The working principle is based on the collection of ice on the icing blade leading edge, and therefore on the measurement of the ice accreted. The LWC is then related to the thickness of ice, the airspeed, the exposure time and the collection efficiency of the blade.

The blade is used to measure the LWC at air temperature of -20°C. The exposure time is adjusted to allow approximately 3mm of ice thickness on the blade leading edge, in order to limit the maximum width of ice and to reduce the variation of the collection efficiency during the test.

9.2.2.2 Hot-Wire LWC Probe

As further instrumentation for LWC measurements, a Droplet Measurement Technologies LWC-100 system is available (Fig. 44).

Fig. 44: DMT LWC-100 probe

The principle for LWC measurement is based on the amount of power required to keep the sensor at constant temperature when water droplets impinging on the probe vaporize. The LWC is linearly related to the difference between wet and convective power losses, and depends on airspeed, temperature and pressure. Typical performance ranges from LWC are 0÷3.0 g/m^3, whereas the TAS required for applying

this technique ranges from approximately 140 to 230 miles per hour.

9.2.3 Liquid Water Content Uniformity Measurement Methods

The Icing Grid is the standard calibration system used in CIRA IWT to measure cloud uniformity and coverage area.

The Icing Grid (Fig. 45) is made of vertical and horizontal stainless steel bars equally spaced in the cross section of the test chamber. The bars are connected to an external frame, fixed to the test section internal walls. Grid mash spacing is 95x105 mm. Thickness of each bar is 3 mm.

In order to get a map of the LWC distribution in the cross-section, all the measurements are converted to relative LWC normalized to the center of the test section. The grid is exposed to the icing cloud to allow the ice to build up at -20°C air temperature. The number of measuring points changes in function of the tests section dimensions and ranges from 360 (MTS) to 220 (STS).

Digital calipers are used for fast thickness measurements.

Fig. 45: Icing Grid installed in the IWT MTS

9.3 AERODYNAMIC INSTRUMENTATION

The following aerodynamic instrumentation is available for flow field characterization.

9.3.1 Hot Wire

A dedicated hot wire system IFA 100 TSI system is available for turbulence measurements. A probe rotator allows angular calibrations for the 2D cylindrical probes (X probes). The system is equipped with a calibrator manufactured by Dantec, a signal recorder provided by Racall Recorder Storeplex and several probes (wedge probes, hot films and hot wires).

9.3.2 Flow Angularity Probe

A Unite Sensor SBF-12 five holes conical probe is available for flow angularity measurements. The central hole measures the total pressure whereas the static pressures measured on the surface of a cone of 30deg of aperture angle are used for the flow angularity measurement.

9.3.3 Temperature Probe

A model 102 AU1AF deiced, platinum resistance type total temperature sensor is available total temperature measurements.

The sensing element consists of a platinum wire having 500 OHMS resistance at 0°C and it is insulated and hermetically sealed within two concentric tubes. The sensing element is protected from impingement of small foreign particles.

The housing can be de-iced in a static temperature range included between -10°C and -35°C.

Main features of the probe are:

- Temperature range: -100÷+350 °C
- Speed range: Up to Mach = 3
- Altitude range: sea level to 30 km
- Accuracy: 0.1 °C

Maximum recovery error is about 0.4% at Mach values ranging between 1 and 3.

9.3.4 Laser Doppler Velocimeter

The CIRA Laser Doppler Velocimeter (LDV) is a special system designed by Aerometrics/TSI Inc., with long focal length

operating in critical environmental conditions (low temperature, high relative humidity, low/high static pressure, etc..), for two-dimensional flow characterisation. The LDV system uses the same transmitting optics as receiver optics, coupled in one probe unit (transceiver) working in backscatter mode.

10.0 IWT PERFORMANCE

As previously said, CIRA IWT can work both as an Icing Wind Tunnel or an Aerodynamic Wind Tunnel. The following section briefly describes the main performance of the facility in both the configurations.

Aerodynamic and icing calibration of IWT test sections are performed in accordance with the Aerospace Recommended Practice described in the SAE-ARP 5905 [1].

Instrumentation used for aero-cloud characterisation is in agreement to the specifications described in ref. [1] and in the document SAE AIR 4906 [2].

10.1 ICING TESTING CAPABILITIES

At the time of editing the present document, the MTS and STS icing calibration has been already completed. ATS icing calibration is scheduled for the first half of year 2005.

Results of MTS icing calibration can be found in ref. [3]. Further results of MTS and STS calibration are reported in ref. [4, 5] and can be made available upon specific request.

Figs. 46 and 47 show the icing cloud operative envelope in terms of LWC (gr/m^3) vs. MVD (μm) for the MTS, at airspeed respectively of 40 m/s and 100 m/s (30% and 80% of max achievable velocity). The envelopes corresponding to three SBS configuration (160, 304 and 500 spraying nozzles) are reported in each figure.

The final cloud envelopes for the STS are available upon request.

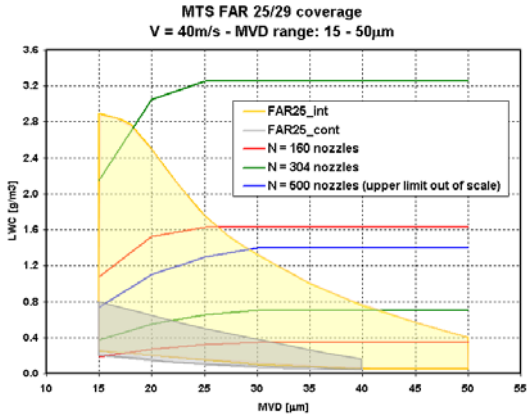
MTS FAR 25/29 coverage
V = 40m/s - MVD range: 15 - 50μm
FAR25_int
FAR25_cont
N = 160 nozzles
N = 304 nozzles
N = 500 nozzles (upper limit out of scale)
LWC [g/m3]
MVD [μm]

Fig. 46: MTS icing cloud envelope at 40 m/s

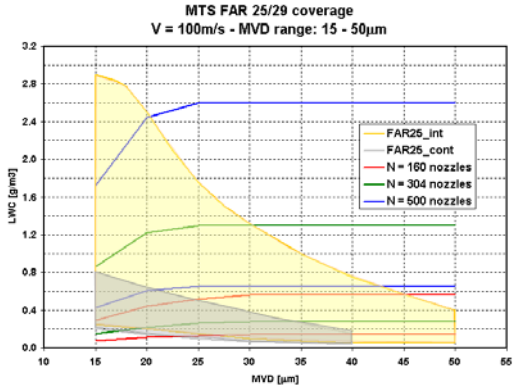

Fig. 47: MTS icing cloud envelope at 100 m/s

Figures 48 and 49 provide an example of contour maps of the liquid water content in the MTS and the STS respectively. The contour maps were developed by using a dimensionless ratio between the liquid water content at a given location of the test section LWC(y,z) and the liquid water content $LWC_c(y_c,z_c)$ at the center of the test section.

Fig. 48 shows a typical cloud uniformity result in the MTS. The measurement was performed at 83 m/s, spraying with 304 active nozzles.
A ±20% cloud uniformity has been obtained in a 1.6 m. high by 1.5 m. wide area.

Fig. 49 represents the cloud uniformity in the STS, in a 0.65 m. high by 0.8 m. wide area. This area represents a typical test region for icing tests aimed at the development and/or certification of both

probes and 2D airfoil equipped with de/anti-icing systems.
A ±10% uniformity is reached within the above specified region. This measurement has been performed at 140 m/s, spraying with 304 active nozzles.

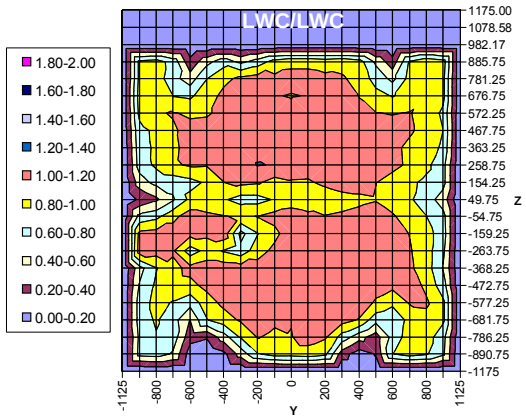

Fig. 48: Cloud uniformity in the MTS at 83 m/s

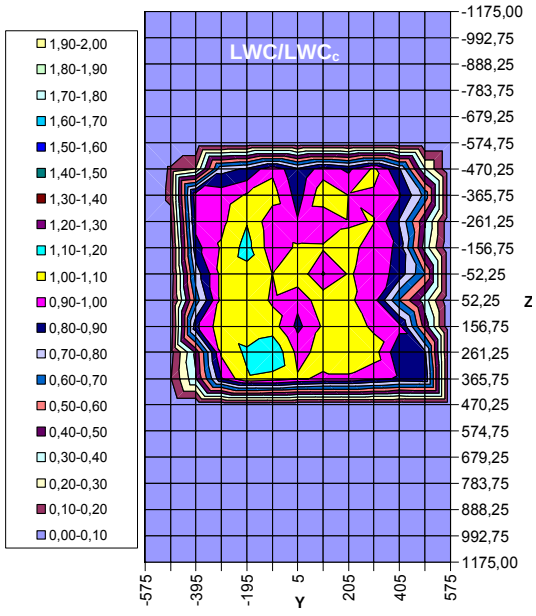

Fig. 49: Cloud uniformity in the STS at 140 m/s

10.2 AERODYNAMIC TESTING CAPABILITIES

As an aerodynamic wind tunnel, the CIRA IWT can perform low and high subsonic aerodynamic testing at high Reynolds numbers, comparable to much larger facilities (Fig. 50).

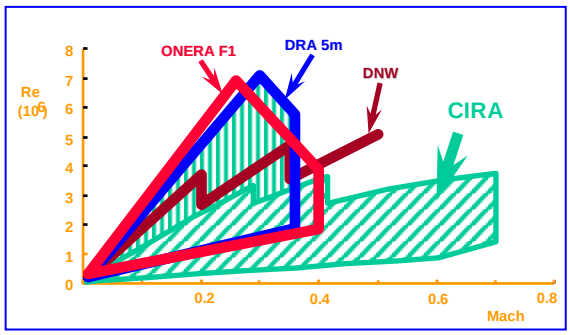

Fig. 50: IWT aerodynamic operative envelope

For a complete definition of the aerodynamic features, flow qualities are evaluated, for each test section, both in tunnel aerodynamic (screen module installed in settling chamber) and icing (SBS module installed in settling chamber) configuration. By now, MTS aerodynamic calibration has been already completed. Results are shown in ref. [3, 6]. STS and ATS aerodynamic calibration will be performed within the first half of year 2005.

Table 5 summarizes the flow qualities (velocity, angularity, temperature and turbulence) in the MTS, in terms of standard deviation of the spatial distribution, with the tunnel set in aerodynamic configuration. Measurements have been performed in a MTS area centered in the model center of rotation, at two velocities and at static air temperature of 0°C.

Velocity m/s	σ V %	σ α deg	σ β deg	σ Ts °C	Tux %	Tuz %
65	0.14%	0.093°	0.087°	0.057	0.14	0.21
110	0.11%	0.097°	0.097°	0.32	-	-

Tab. 5: MTS flow qualities (aero configuration)

Longitudinal and transverse turbulence distribution at V=65 m/s is shown in fig. 51.

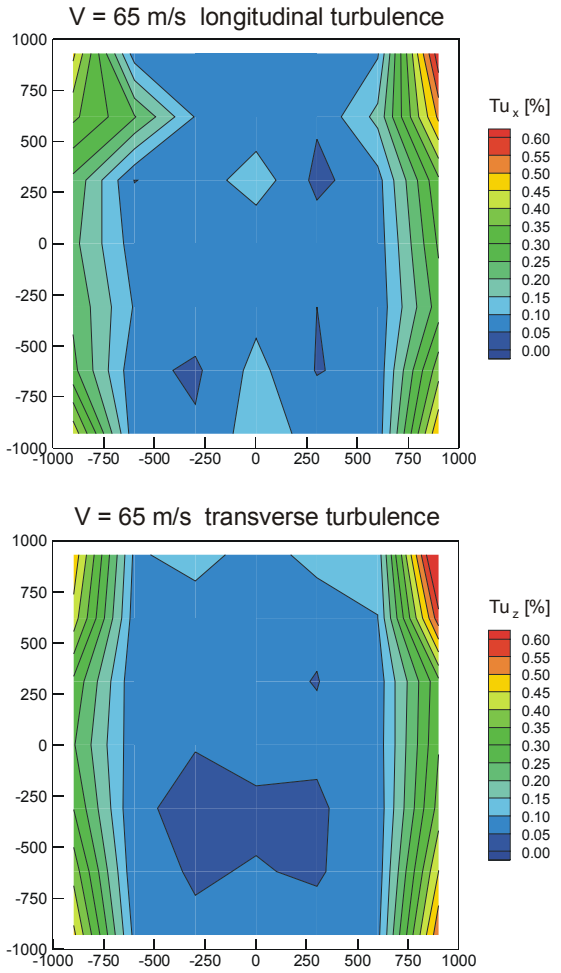

Fig. 51: Turbulence distribution in the MTS

Tab. 6 shows, with the tunnel set in icing configuration, flow angularities and static air temperature standard deviation in the MTS at the following test conditions:

- airspeed of about 104 m/s,
- test section static air temperature - 20°C,
- ambient static pressure,
- spray bar air pressure equal to 0 bar (no blowing) and 6 bar.

Airspeed	Pair	σ α	σ β	σ Ts
103.9m/s	0 bar	0.28°	0.15°	0.30 °C
104.2m/s	6 bar	0.27°	0.16°	0.28 °C

Tab. 6: MTS flow qualities (icing configuration)

Static air temperature distribution, at the same test conditions, is finally shown in Fig. 52.

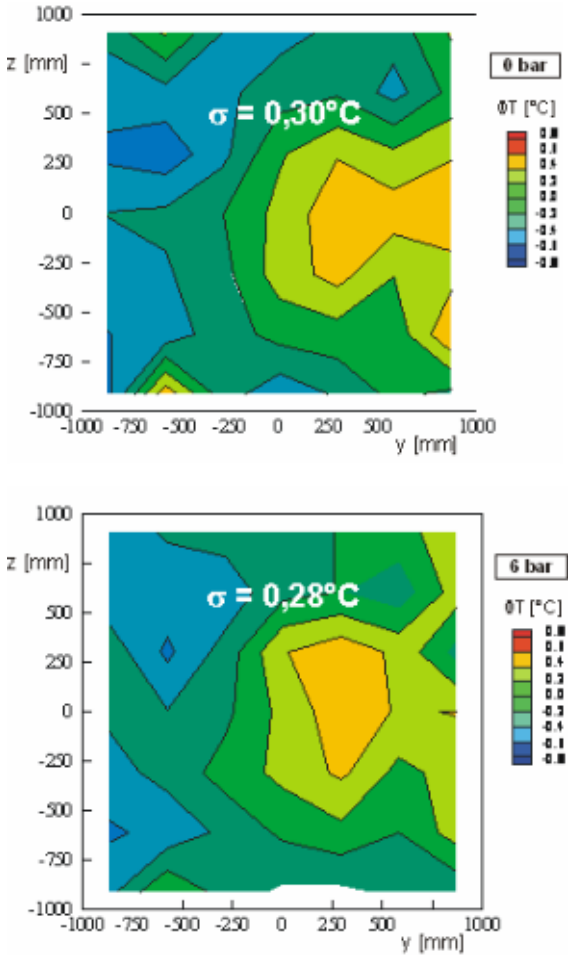

Fig. 52: Static temperature uniformity in MTS

11.0 RESEARCH ACTIVITIES

Since a few years, CIRA is engaged in the development of experimental methodologies to be following applied in the IWT. Specifically, the evaluation of the aerodynamic performance degradation due to severe ice shapes, through the application of non-intrusive measurement techniques, such as Particle Image Velocimetry (PIV) and Pressure Sensitive Paint (PSP), has reached a fine state of maturity. These techniques are in the process to be applied in icing environment in CIRA IWT.

Other measurement techniques for ice shape characterization, determination of microphysics properties of icing clouds (particle sizing, shape, temperature velocity) are in a developing phase.

11.1 PARTICLE IMAGE VELOCIMETRY

CIRA uses PIV technique since more than ten years. PIV has now reached a mature state and is applied in a wide number of industrial facilities spacing from naval towing tanks to aerodynamic wind tunnels.

CIRA PIV equipment mainly consists of several lasers synchronised with three SUPER VGA cameras, optics, two commercial software for data-processing and different in-house software tools under continuous development.

CIRA PIV application in the icing field has started in year 2000 with some measurements aimed at determining performance degradation on ice accreted models. Figs. 53 and 54 respectively report the used models for these activities and an example of the achieved results.

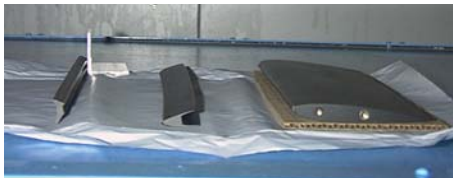

Fig. 53: NACA 0012 with different ice shapes

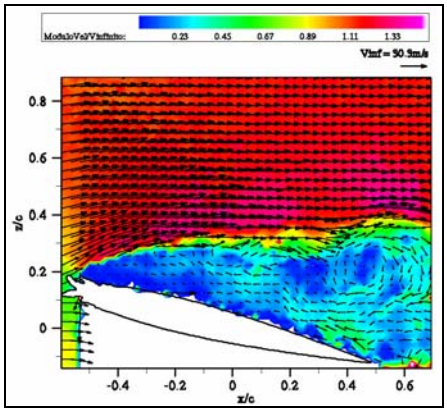

Fig. 54: PIV measurement on ice accreted model

11.2 PRESSURE SENSITIVE PAINT

PSP technique provides continuous pressure field on a model through the application of specific paints on the model surface.

CIRA PSP system is briefly made up of one 16 bit b/w CCD camera equipped with a filter-wheel allowing the insertion up to four optical filters, six LED lamps emitting at 405/464 nm, one TSP/PSP calibration chamber, a commercial software and several tools in-house developed for data-processing.

Since 2001 CIRA started using PSP technique for the study of performance degradation of ice accreted models at low speeds. Figs. 55 and 56 show a typical result of these activities.

Fig. 55: NACA 0012 ice accreted model

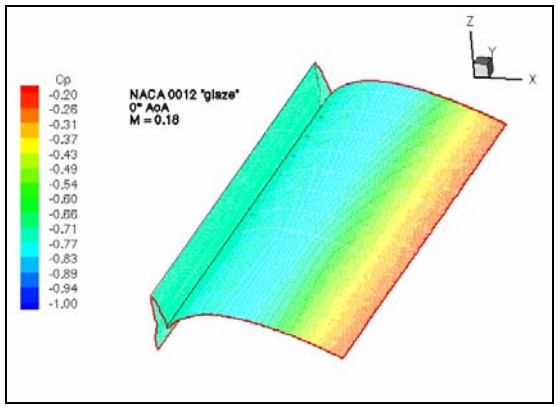

Fig. 56: PSP flow-field on NACA 0012 model at M=0.18

12.0 SAFETY ISSUES

All the external personnel attending the tests are subject to instructions and safety regulation applicable in the CIRA facility. The customer has to provide to CIRA a list of personnel and sub-contractors, mentioning name, position and activities to be carried out by these persons.

12.1 HAZARDS

Some potential hazards have to be taken into account during test preparation and execution. The main ones are listed below:

- Hot and cold fluids
- High pressure pipe
- Electrical shocks
- Laser light exposure
- Noise
- Mechanical hazards
- Slip possibility due to wet/iced floor

Suitable indications are positioned in critical areas; nevertheless IWT users are not allowed to operate any subsystem of the facility.

Before starting the test program the potential hazards will be showed and discussed. IWT users will also be informed about safety procedures.

12.2 PROTECTION EQUIPMENTS

Individual protection equipments for activities to be performed in test sections in icing conditions, as well as impact protection helmets and noise protection taps are provided by CIRA and are available on site. Other personal equipment needed for workshop activities will not be provided by CIRA. IWT users shall have its own personal protection devices such as working gloves and shoes, to be used for model mounting and assembly in the model preparation area.

12.3 EMERGENCY PROCEDURES

CIRA emergency procedures will be showed to IWT users. If required, all people in the IWT area shall follow CIRA safety responsible instructions.

13.0 TEST CAMPAIGN GENERAL ARRANGEMENT

This paragraph describes the main steps of a general test campaign in CIRA IWT.

Delivery of test article

Model shipping to CIRA site, as well as model insurance for shipping and permanence at CIRA site, is in charge of the customer.

Reception of material

Together with the test article, the customer shall provide a detailed list of delivered material. Upon reception of the material, CIRA will verify the compliance between what specified in the list and what received. CIRA will also verify the physical integrity of the material by visual inspection, before acceptance. In case of non-conformity between the shipped material and the shipping bill, CIRA will send to the customer immediate notification.

Test article assembly

Model mounting in the selected test section and model preparation are generally made outside the wind tunnel, in the model preparation area, where instrumentation functional checks can be also performed. As a standard procedure, model instrumentation is provided by the customer, whereas CIRA provides connections to the IWT Data Acquisition System. However, upon customer request, model instrumentation can be supplied by CIRA, provided that a technical specification of the instrumentation is made available by the customer.

Interfaces and wind tunnel adaptations for model installation can be either provided by CIRA or by the customer, upon agreement

between the parties. Handling operations are provided either by CIRA or by customer personnel.

After model mounting, the test section is installed in the wind tunnel and the facility setup is completed.

Preliminary tests

Before starting the productive tests, some functional checks and at least one preliminary icing test are performed by CIRA. These tests are aimed at verifying proper operation of the instrumentation, assessing test assembly compliance with the wind tunnel and checking the test procedures. Type and number of preliminary tests can be agreed between the parties.

Stress calculations and aerodynamic loads on the model must be provided by the customer before starting the activities, and are verified during the preliminary tests if possible. A safety factor of 3 is required to be used by the customer as a minimum.

Testing

The CIRA IWT runs on a single shift of 8 hours per day. In very special cases, upon customer request, a different working time can be agreed.

The time required for a single test is strongly affected by the operations to be performed after the run, such as ice accretion measurements and photos.

During the test, the customer is allowed in the control room, having visual access to all the PCs and videos and actively participating to the test itself. Nevertheless, during the test, the CIRA appointed test engineer is the only one entitled to lead the test and to decide about stopping the run if any problem related to the wind tunnel and/or the instrumentation should occur.
Upon request, the use of a dedicated computer for specific data analysis can be arranged during the test session.
In general, CIRA test engineer is available for data interpretation and technical discussion after the test.

Within the following day, CIRA provides to the customer raw data of test parameters, videos and images of performed runs.

Test article restitution

At the end of the test campaign, material shipped to CIRA by the customer is returned. De-assembly operations are executed by CIRA personnel.

Model shipping from CIRA site, as well as model insurance for shipping, is in charge of the customer.

Test report

After the end of test activities, a final test report including test conditions, compliance between the planned test matrix and the performed one, raw data, photos and videos is delivered by CIRA to the customer. Test report is provided both on paper and electronic format.

14.0 TEST REQUEST PROCEDURE

To perform a test campaign in CIRA IWT, a formal request has to be submitted. The following basic steps can be identified as a standard procedure to be followed.

Preliminary information

The customer sends to CIRA an icing test campaign inquiry. At least the following issues must be included in the request:

- Desired test period
- Goal of the tests
- Number of runs
- Speed
- Temperature
- Altitude
- Droplet size and Liquid Water Content
- Specific measurements to be performed during and after the tests
- Test article configuration (e.g. dimensions, angle of attack)
- Run time for each test
- Additional features (e.g. mass flow simulation, de-icing system simulation)

Based on the available information, CIRA issues a preliminary quotation of the activity and provides Rough Order of Magnitude

(ROM) cost estimation for the activity. This ROM evaluation is just indicative and is to be considered for budgetary purpose only. Moreover, a possible testing window for the activity is indicated.

Together with the ROM cost estimation, CIRA provides the hypotheses considered in its analysis, as well as all the items not completely specified in the customer requirement and strongly affecting cost and time evaluation.

Request of offer

The customer sends to CIRA an official request of offer, including a letter of intent to perform the activities, and a technical specification of the test program.

Technical specification must include detailed information at least about the following issues:

- Test plan
- Model mounting details
- Instrumentation
- Model aerodynamic and stress loads
- Data acquisition and data reduction
- Reporting

Together with technical details, specific requests for quality regimen and test classification must be indicated at this time.

After CIRA internal analysis, a meeting at CIRA is arranged in order to clarify all the technical aspects, if necessary. Usually, 1 to 2 days are required. All technical aspects having significant impact on feasibility, cost and time evaluations of the activity, are frozen at the end of the meeting.

It has to be remarked that the time needed for completing the test program can be strongly affected by the chronological order of the tests. As a standard practice, CIRA appointed test engineer cooperates with the customer in arranging and tuning the test matrix, also taking into account wind tunnel operations, in order to optimize the test program.

Commercial proposal

After the meeting, CIRA issues a commercial proposal to the customer.

Cost of the activity, payment terms, and CIRA general terms and condition of sale for testing services are included in the proposal. CIRA technical specification, describing the Scope of Work of the activity, is also attached as integral part of the proposal itself. CIRA technical specification is the reference basis for the definition of the commercial proposal.

A testing window is also assigned, based on the policy described in the following section.

Contract formalization

The contract is finalized when the customer confirms the order, by issuing a P.O. order, or when both the parties sign a contract.

At this time, the assigned testing slot becomes committed.

Once the activity has been committed, CIRA test engineer and customer technical reference person can cooperate for further tuning of the program, if necessary. One or more meetings can be arranged in case of necessity.

14.1 TESTING SLOT ASSIGNMENT PROCEDURE

CIRA has a policy for assigning testing windows in the Icing Wind Tunnel.

A testing window is defined as “assigned” at the delivery of an official request of offer for a specific test campaign, and becomes “committed” when the perspective client issues a contract or a P.O. order.

CIRA "assigns" testing windows sequentially, based on the time of issuance of offers.

The “assigned” test window is however subject to confirmation to become "committed", since priority is given to clients which are confirming the order, i.e. issuing a P.O. order or a contract.

15.0 CONTACT POINTS

CIRA mail address is:

CIRA scpa
Via Maiorise s.n.c.
81043 Capua (CE) - ITALY

CIRA phone operator: +39 0823 623111

CIRA entrance desk: +39 0823 623001

CIRA Aeronautical Ground Testing Facilities, Head is:

Ludovico Vecchione
Phone:+39 0823 623918
Cell : +39 348 7361311
Fax: +39 0823 969272
E-mail: **l.vecchione@cira.it**

Assistant Phone: +39-0823-623963
Fax: +39-0823-969272

CIRA Icing Test Laboratory, Head is:

Francesco Ferrigno

Phone:+39 0823 623048
Fax: +39 0823 969272
E-mail: **f.ferrigno@cira.it**

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2. "Droplet Size Instrumentation Used in Icing Facilities", SAE-AIR-4906.
3. B. M. Esposito, A. Ragni, F. Ferrigno, L. Vecchione, "Cloud Calibration Update of the CIRA Icing Wind Tunnel", SAE 2003-01-2312, June 2003.
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